Grade 12 A/L ICT

Lesson 2: Introduction to Computer

- 2.1 History of Computers: Generations, Processors and Classification
- 2.2 Computer Hardware: Input, Output, CPU, Storage and Interfaces
- 2.3 Von Neumann Architecture: Stored Program, CPU and the Fetch–Execute Cycle
- 2.4 Memory Hierarchy: Registers, Cache, RAM, ROM and Secondary Storage

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Grade 12 A/L ICT · Lesson 2

2.1 History of Computers: Generations, Processors and Classification

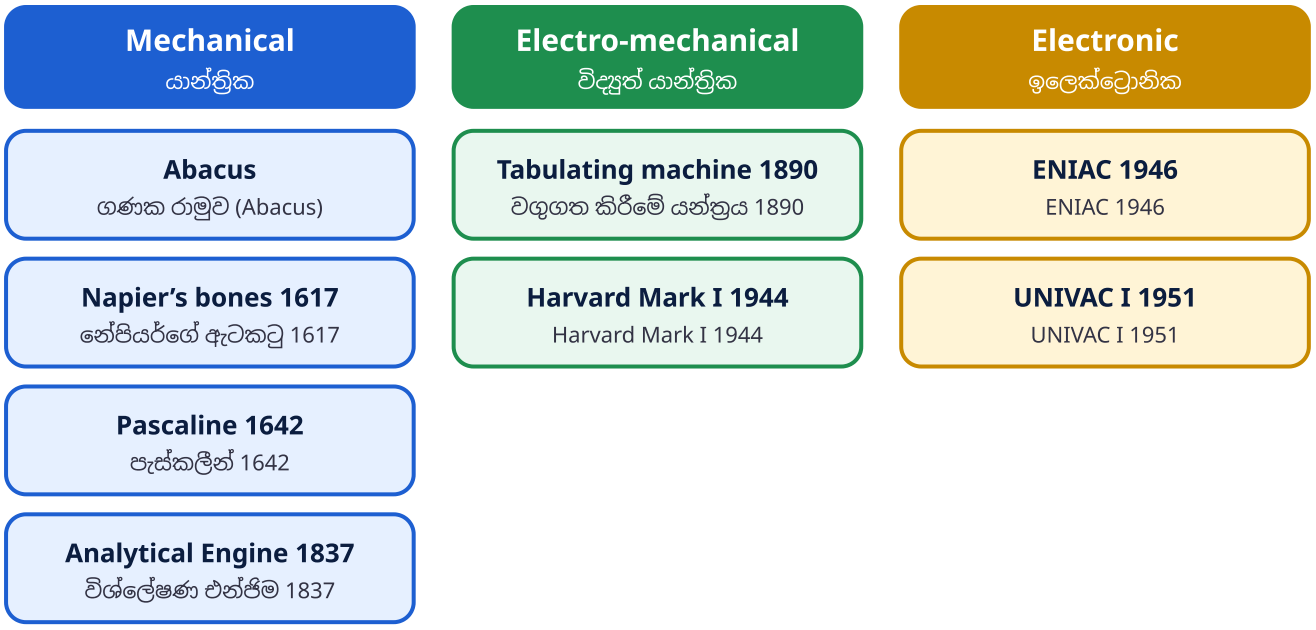
Syllabus 2.1. People have always wanted machines that help them count and calculate. The story goes from the **abacus** to **mechanical** machines, then **electro-mechanical** machines, and finally **electronic** computers. Electronic computers grew through **five generations**, each smaller, faster and cheaper than the one before. In this part you also learn how **processors** evolved and how we **classify** computers by technology, by purpose and by size.

1. Early calculating aids

Before electricity, people used **mechanical** aids that worked with beads, rods, gears and wheels. Later, **electro-mechanical** machines used electric motors and switches (relays) to move mechanical parts. Then came fully **electronic** computers with no moving parts for calculation.

Aid / machine	Year and person	Type	What it did
Abacus	Ancient (about 2400 BC)	Mechanical (moved by hand)	Beads on rods for adding and subtracting
Napier’s bones	1617, John Napier	Mechanical	Numbered rods for multiplication
Slide rule	1620s, William Oughtred	Mechanical (analog)	Sliding scales for multiply and divide
Pascaline	1642, Blaise Pascal	Mechanical	Gear wheels that add and subtract
Stepped Reckoner	1673, Gottfried Leibniz	Mechanical	Could also multiply and divide
Jacquard loom	1801, Joseph Jacquard	Mechanical	Punched cards controlled the weaving pattern
Difference and Analytical Engine	1822 and 1837, Charles Babbage	Mechanical	Analytical Engine had input, store, mill (processor) and output – the idea of a modern computer
Tabulating machine	1890, Herman Hollerith	Electro-mechanical	Read punched cards to count the US census
Harvard Mark I	1944, Howard Aiken	Electro-mechanical	Large relay calculator, 15 m long
ENIAC	1946, Eckert and Mauchly	Electronic	About 18,000 vacuum tubes; first general purpose electronic computer

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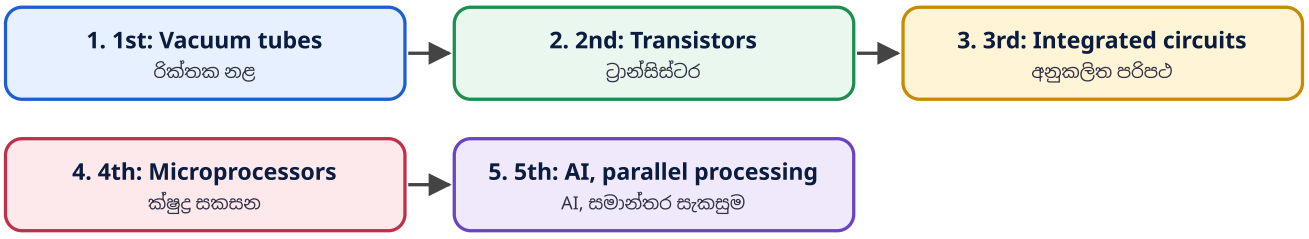
Mechanical, electro-mechanical and electronic aids.

💡 **Charles Babbage** is called the "father of the computer". **Ada Lovelace** wrote steps for his Analytical Engine, so she is called the first programmer.

2. Generations of computers

A **generation** is a stage in computer history marked by the main **electronic part** used to build it. Each new part made computers smaller, faster, more reliable, cheaper and lower in power use.

Generation	Period	Main technology	Examples
1st	1940–1956	Vacuum tubes	ENIAC, UNIVAC I
2nd	1956–1963	Transistors	IBM 1401, IBM 7090
3rd	1964–1971	Integrated circuits (ICs)	IBM System/360
4th	1971–present	Microprocessors (VLSI)	IBM PC, Apple Macintosh, laptops
5th	Present and future	AI, parallel processing (ULSI)	AI systems, supercomputers



The five generations of computers.

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1st – vacuum tubes
Huge, very hot, used much power, often failed. Machine language only. Punched cards for input.

2nd – transistors
Smaller, cooler and more reliable. Assembly language and early high level languages (FORTRAN, COBOL). Magnetic core memory.

3rd – integrated circuits
Many transistors on one silicon chip. Keyboards, monitors and operating systems; many users at once.

4th – microprocessors
The whole CPU on one chip (VLSI). Personal computers, GUIs, networks and the Internet.

5th – AI and parallel
Artificial intelligence, parallel processing, natural language and voice. ULSI chips. Still developing.

3. Evolution of processors

A **microprocessor** is a CPU built on one chip. The first was the **Intel 4004 (1971)**. Since then the number of **transistors**, the **word size** (bits handled at once) and the **clock speed** have grown, and now one chip has several **cores**.

Year	Processor	Word size	Transistors
1971	Intel 4004	4-bit	2,300
1974	Intel 8080	8-bit	4,500
1978	Intel 8086	16-bit	29,000
1985	Intel 80386	32-bit	275,000
1993	Intel Pentium	32-bit	3.1 million
2006	Intel Core 2 Duo	64-bit, 2 cores	291 million
2020	Apple M1	64-bit, 8 cores	16 billion

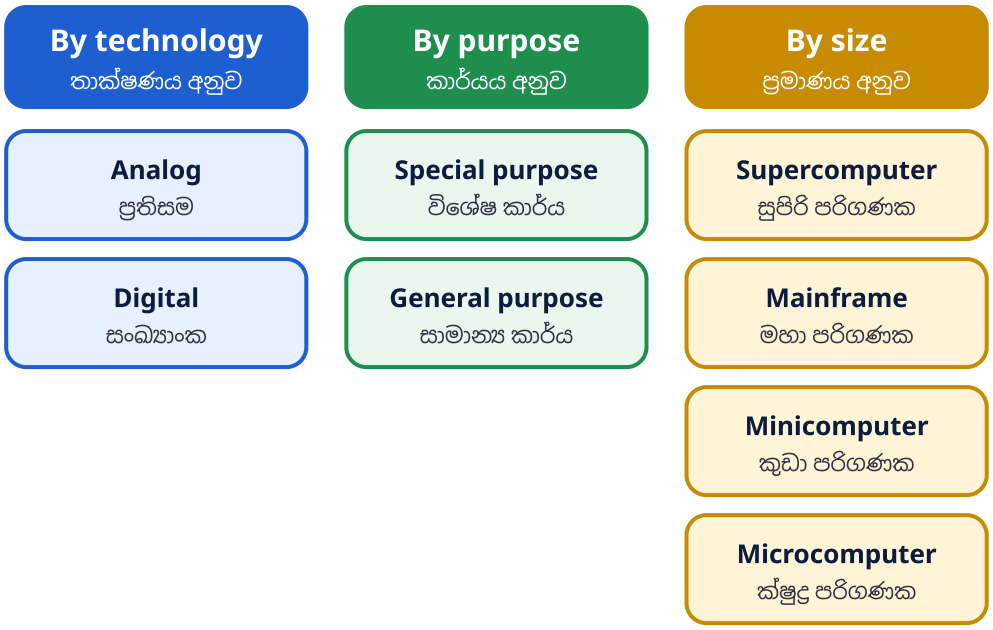
Moore's law (Gordon Moore, 1965): the number of transistors on a chip doubles about every two years.

🧱 **Worked example: Moore's law: the Intel 4004 (1971) had about 2,300 transistors. If the count doubles every 2 years, how many transistors would a chip have in 2011?**
Years = 2011 − 1971 = 40. Doublings = 40 ÷ 2 = 20. Count = 2,300 × 2^20 = 2,300 × 1,048,576 = **2,411,724,800** (about 2.4 billion). Real chips in 2011 had about 2.3 billion – the law worked well.

🧱 **Worked example: The Intel 4004 ran at 740 kHz. A modern core runs at 3.7 GHz. How many times faster is the clock?**
3.7 GHz = 3,700,000,000 Hz; 740 kHz = 740,000 Hz. 3,700,000,000 ÷ 740,000 = **5,000 times**.

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4. Classification of computers



Three ways to classify computers.

4.1 By technology: analog and digital

Feature	Analog computer	Digital computer
Data	Continuous values (voltage, pressure, temperature)	Discrete values – digits 0 and 1
Accuracy	Lower – an approximate reading	High – exact digits
Memory	Little or none	Large memory
Examples	Slide rule, analog speedometer, differential analyser	PC, laptop, smartphone

> 💡 A **hybrid computer** joins both: for example a hospital ICU monitor measures the heart (analog) and shows numbers and stores records (digital).

4.2 By purpose: special purpose and general purpose

- **Special purpose** – made for one job only, with a fixed program. Examples: washing machine controller, traffic light controller, ATM, car engine computer, digital camera.
- **General purpose** – can do many different jobs by loading different programs. Examples: desktop PC, laptop, smartphone.

4.3 By size: super, mainframe, mini and micro

Type	Size and power	Users	Uses
Supercomputer	Fastest; thousands of processors working in parallel	Research teams	Weather forecasting, climate, space, nuclear research, AI training

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Mainframe	Very large and reliable; huge storage	Hundreds or thousands at once	Banks, airlines, insurance, government records
Minicomputer (mid-range)	Smaller than a mainframe	Tens of users	A department, small business, factory control
Microcomputer	Small; one microprocessor	Usually one user	Desktop, laptop, smartphone, tablet, phablet

Mobile microcomputers: a **smartphone** is a phone with a full operating system and apps; a **tablet** is a flat touch-screen computer, usually 7 to 13 inches, often without phone calls; a **phablet** is a large smartphone (about 6 to 7 inches) – between a phone and a tablet.

🚀 **Beyond the syllabus (2026 update)** *Not required for the exam – read for interest.* **ARM and Apple silicon.** In 2026 most phones, tablets and many laptops use **ARM** processors, which give good speed with low power. Apple's M-series chips (M1 in 2020, now M4 and newer) put the CPU, GPU, AI engine and memory in one package called a **system on a chip (SoC)**. **Quantum computers** are a new idea: they use **qubits** that can be 0 and 1 at the same time (superposition). Companies like IBM and Google have chips with over 100 qubits, but they are still experimental and need very cold temperatures.

Key Words

Abacus – An early hand-moved calculating aid with beads on rods.

Pascaline – A mechanical adding machine with gear wheels made by Pascal in 1642.

Analytical Engine – Babbage's planned machine with input, store, mill and output.

Electro-mechanical – Machines that use electric relays and motors to move mechanical parts.

Vacuum tube – The switching part of first generation computers.

Transistor – A small semiconductor switch used from the second generation.

Integrated circuit – Many transistors made together on one silicon chip.

Microprocessor – A complete CPU on a single chip.

Moore's law – Transistors on a chip double about every two years.

Analog computer – A computer that works with continuous values.

Digital computer – A computer that works with discrete digits 0 and 1.

Special purpose computer – A computer built for one fixed job.

Supercomputer – The fastest type, used for huge scientific calculations.

Mainframe – A large reliable computer serving thousands of users at once.

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Phablet – A large smartphone between a phone and a tablet in size.

Sample Q&A

1. Name two mechanical calculating aids and give one fact about each.

> **Answer:** Pascaline (1642, Blaise Pascal) – gear wheels that add and subtract. Analytical Engine (1837, Charles Babbage) – had input, store, mill and output, like a modern computer.

2. What is the main technology of each computer generation?

> **Answer:** 1st vacuum tubes; 2nd transistors; 3rd integrated circuits; 4th microprocessors (VLSI); 5th AI and parallel processing (ULSI).

3. Give three problems of first generation computers.

> **Answer:** They were very large, produced a lot of heat and used much electricity; vacuum tubes failed often; they could be programmed only in machine language.

4. Distinguish analog and digital computers.

> **Answer:** An analog computer works with continuous values such as voltage and gives approximate results. A digital computer works with discrete digits 0 and 1 and gives exact results.

5. Why is a washing machine controller a special purpose computer?

> **Answer:** It is built to do only one job – control washing – with a fixed program that the user cannot change.

6. Which type of computer would a bank use for all its accounts, and why?

> **Answer:** A mainframe, because it is very reliable, stores huge amounts of data and serves thousands of users and transactions at the same time.

MCQ

1. Which calculating aid was made by Blaise Pascal in 1642?

A. Napier’s bones
B. Abacus
C. Pascaline
D. ENIAC
E. Analytical Engine

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2. Who is called the “father of the computer”?

A. John Napier
B. Herman Hollerith
C. Blaise Pascal
D. Gordon Moore
E. Charles Babbage

3. Hollerith’s tabulating machine (1890) is an example of a:

A. Electro-mechanical machine
B. Fourth generation computer
C. Quantum computer
D. Fully electronic computer
E. Purely mechanical aid

4. Which generation used transistors as the main part?

A. Third
B. Fourth
C. Fifth
D. Second
E. First

5. The first microprocessor, the Intel 4004, was released in:

A. 1946
B. 1981
C. 1971
D. 1956
E. 1964

6. Integrated circuits are the main technology of the:

A. Second generation
B. Third generation
C. First generation
D. Mechanical era
E. Fifth generation

7. Using Moore’s law, 2,300 transistors in 1971 becomes about how many in 2011?

A. About 2.4 billion
B. About 2.4 million
C. About 92,000
D. About 24 billion
E. About 46,000

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8. Which is an analog device?

A. A calculator app
B. A laptop
C. A slide rule
D. A digital watch
E. A smartphone

9. A traffic light controller is best described as a:

A. Supercomputer
B. Mainframe
C. Analog slide rule
D. General purpose computer
E. Special purpose computer

10. Weather forecasting for a whole country needs a:

A. Tablet
B. Supercomputer
C. Minicomputer
D. Washing machine controller
E. Phablet

11. A smartphone with a 6.7-inch screen is often called a:

A. Mainframe
B. Analog computer
C. Plotter
D. Minicomputer
E. Phablet

12. Which statement about fourth generation computers is TRUE?

A. They began in 1946
B. They use only machine language
C. They have no operating system
D. The whole CPU is on one chip
E. They use vacuum tubes

13. Which term means: “An early hand-moved calculating aid with beads on rods”?

A. Transistor
B. Microprocessor
C. Analytical Engine
D. Abacus
E. Digital computer

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14. Which term means: “A mechanical adding machine with gear wheels made by Pascal in 1642”?

A. Pascaline
B. Special purpose computer
C. Moore’s law
D. Electro-mechanical
E. Integrated circuit

15. Which term means: “Babbage’s planned machine with input, store, mill and output”?

A. Analytical Engine
B. Vacuum tube
C. Analog computer
D. Supercomputer
E. Microprocessor

16. Which term means: “Machines that use electric relays and motors to move mechanical parts”?

A. Moore’s law
B. Transistor
C. Mainframe
D. Digital computer
E. Electro-mechanical

17. Which term means: “The switching part of first generation computers”?

A. Analog computer
B. Vacuum tube
C. Phablet
D. Special purpose computer
E. Integrated circuit

18. Which term means: “A small semiconductor switch used from the second generation”?

A. Abacus
B. Microprocessor
C. Transistor
D. Digital computer
E. Supercomputer

19. Which term means: “Many transistors made together on one silicon chip”?

A. Special purpose computer
B. Integrated circuit
C. Pascaline
D. Mainframe
E. Moore’s law

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20. Which term means: "A complete CPU on a single chip"?

A. Supercomputer
B. Phablet
C. Analytical Engine
D. Microprocessor
E. Analog computer

Structured Questions

1. (a) Name the main technology of the first three computer generations. (b) Give one advantage of each new generation over the one before. *(5 marks)*

> (a) 1st vacuum tubes; 2nd transistors; 3rd integrated circuits; (b) transistors were smaller, cooler and more reliable than tubes; ICs put many transistors on one chip, so computers became smaller and cheaper.

2. Arrange these in time order and name the type (mechanical, electro-mechanical or electronic): ENIAC, Pascaline, Harvard Mark I, Abacus. *(4 marks)*

> Abacus – mechanical (hand); Pascaline 1642 – mechanical; Harvard Mark I 1944 – electro-mechanical; ENIAC 1946 – electronic.

3. Use Moore's law to estimate the transistors on a chip in 2011 if the Intel 4004 of 1971 had 2,300. Show your working. *(3 marks)*

> 40 years ÷ 2 = 20 doublings; 2^20 = 1,048,576; 2,300 × 1,048,576 = 2,411,724,800 (about 2.4 billion).

4. (a) Distinguish special purpose and general purpose computers with one example each. (b) Is an analog speedometer digital or analog? Why? *(3 marks)*

> Special purpose – one fixed job, e.g. ATM; general purpose – many jobs with different programs, e.g. a PC; (b) analog – the needle shows a continuous value.

5. Suggest the most suitable computer type for each and give a reason: (a) a national bank (b) climate research (c) a student doing homework. *(3 marks)*

> (a) Mainframe – reliable, thousands of users at once; (b) supercomputer – fastest for huge calculations; (c) microcomputer such as a laptop or tablet – cheap, one user.

Summary

- Aids went from mechanical (abacus, Pascaline, Babbage) to electro-mechanical (Hollerith, Mark I) to electronic (ENIAC).

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- Generations: vacuum tubes → transistors → ICs → microprocessors → AI and parallel processing.
- Processors grew from the 4-bit Intel 4004 (1971) to 64-bit multi-core chips; Moore's law – transistors double every two years.
- By technology: analog (continuous) or digital (0 and 1).
- By purpose: special purpose (one job) or general purpose (many jobs).
- By size: super, mainframe, mini and micro – micro includes smartphones, tablets and phablets.

MCQ answer key – 2.1

1. **C** – Pascal's gear adding machine.
2. **E** – He designed the Analytical Engine.
3. **A** – Electric parts read punched cards.
4. **D** – 1956–1963.
5. **C** – It began the fourth generation.
6. **B** – 1964–1971, e.g. IBM System/360.
7. **A** – 20 doublings: 2,300 × 1,048,576.
8. **C** – Continuous scales.
9. **E** – One fixed job.
10. **B** – Huge calculations.
11. **E** – Phone + tablet.
12. **D** – Microprocessor = CPU on a chip.
13. **D** – Abacus – An early hand-moved calculating aid with beads on rods.
14. **A** – Pascaline – A mechanical adding machine with gear wheels made by Pascal in 1642.
15. **A** – Analytical Engine – Babbage's planned machine with input, store, mill and output.
16. **E** – Electro-mechanical – Machines that use electric relays and motors to move mechanical parts.
17. **B** – Vacuum tube – The switching part of first generation computers.
18. **C** – Transistor – A small semiconductor switch used from the second generation.
19. **B** – Integrated circuit – Many transistors made together on one silicon chip.
20. **D** – Microprocessor – A complete CPU on a single chip.

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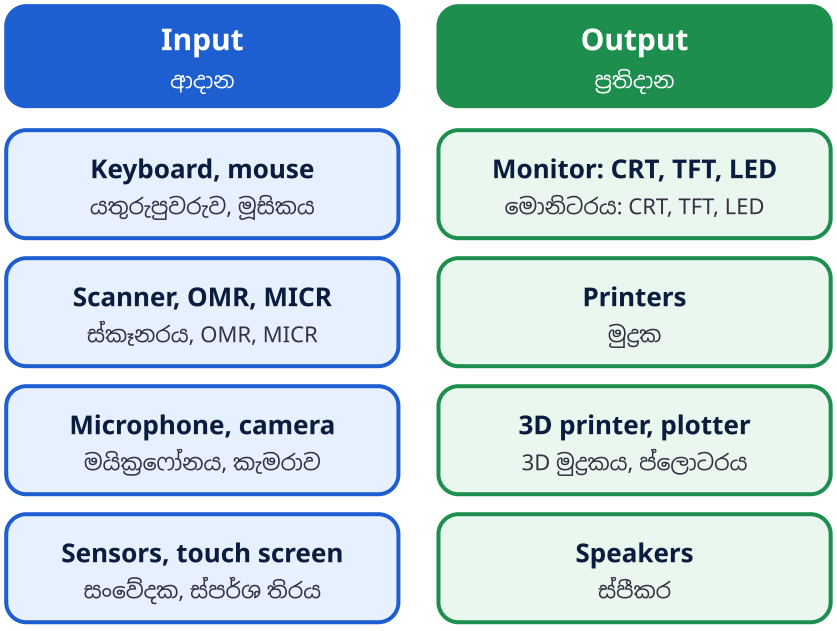
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2.2 Computer Hardware: Input, Output, CPU, Storage and Interfaces

Syllabus 2.2. A computer is a team of hardware parts. **Input devices** bring data in, the **CPU** on the **motherboard** processes it, **output devices** show the results and **storage devices** keep data for later. Each part connects through an **interface (port)** such as USB or HDMI. In this part you learn every device in the syllabus, why **direct entry** is better than typing, how to match a **CPU with a motherboard**, the features of each **storage device**, and why we need **parallel and grid computing**.

1. Input devices

There are two ways to input data. **Keyboard entry**: a person types the data (keyboard, keypad). **Direct entry**: the device reads data straight from the source without typing (barcode reader, scanner, sensors and so on).



Common input and output devices.

Device	What it does	Example use
Keyboard	Keys for letters, digits and commands	Typing a letter
Pointing devices (mouse, trackball, joystick)	Move a pointer and click	Choosing a menu item; games
Touch pad	Finger moves on a flat pad move the pointer	Laptops

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Remote control	Sends infrared or radio signals	TV, projector
Touch screen	Screen that senses touch – input and output together	Phones, ATMs, kiosks
Magnetic strip reader	Reads the magnetic strip on a card	Old bank cards, hotel keys
Barcode reader	Reads black and white bars with light	Supermarket checkout, library
Smart card reader	Reads a chip inside a card	Chip bank cards, e-NIC
Scanner	Turns a paper page into a digital image	Copying documents
Digital camera / video camera	Capture photos or moving pictures	Photos, CCTV
Web cam	Small camera for live video over a network	Online classes
Microphone	Turns sound into a signal	Voice calls, voice commands
Sensors	Measure light, heat, pressure, motion and so on	Weather station, smart home
Graphic tablet / digitizer	A pen on a flat board turns drawings into digital data	Drawing, maps, design
MICR reader	Reads characters printed in magnetic ink	Bank cheques
OMR reader	Reads pencil marks in fixed boxes	MCQ answer sheets
OCR	Software and scanner read printed text as characters	Passports, number plates

1.1 Advantages of direct entry over keyboard entry

- **Faster** – a barcode is read in less than a second.
- **More accurate** – no typing (transcription) errors.
- **Less labour and cost** – fewer data entry staff are needed.
- **Works all the time and in hard places** – sensors work 24 hours, even in dangerous or remote places.
- **Large amounts of data** can be captured quickly, e.g. thousands of OMR sheets.

2. Output devices

Device	How it works	Features
CRT monitor	An electron beam lights phosphor dots on a glass tube	Heavy, deep, uses much power; now old
TFT (LCD) monitor	Liquid crystals controlled by thin film transistors	Flat, light, less power than CRT

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LED monitor	An LCD panel lit by light emitting diodes	Thinner, brighter, lowest power, long life
Dot matrix printer	Impact: pins hit an ink ribbon	Noisy, low quality, cheap to run; prints carbon copies
Inkjet printer	Non-impact: sprays tiny ink drops	Good colour photos; cheap printer, costly ink
Laser printer	Non-impact: a laser charges a drum; toner powder sticks and is heated on	Fast, sharp, quiet; low cost per page for many pages
3D printer	Builds a solid object layer by layer (often melted plastic)	Models, spare parts, medical implants
Graph plotter	Pens draw lines on large paper	Accurate large drawings: plans, maps, CAD
Speakers	Turn electrical signals into sound	Music, alarms, voice output

3. The CPU and the motherboard

The **motherboard** is the main circuit board. It holds the CPU socket, RAM slots, chipset, expansion slots (PCIe) and ports, and connects all parts. A CPU works only on a motherboard that is **compatible** with it.

Socket
The CPU pins or pads must match the socket, e.g. Intel LGA 1700 or AMD AM5.

Chipset and BIOS
The chipset must support the CPU family; a BIOS/UEFI update may be needed.

Memory type
The board and CPU must support the same RAM type, e.g. DDR4 or DDR5.

Power
The board must supply enough power for the CPU (TDP in watts).

Form factor
The board size (ATX, micro-ATX, mini-ITX) must fit the case.

Evolution of the CPU package: early chips had two rows of pins (**DIP**); later chips had many pins underneath (**PGA**); modern Intel and AMD desktop chips have flat pads and the pins are in the socket (**LGA**). Laptop and phone CPUs are soldered straight onto the board.

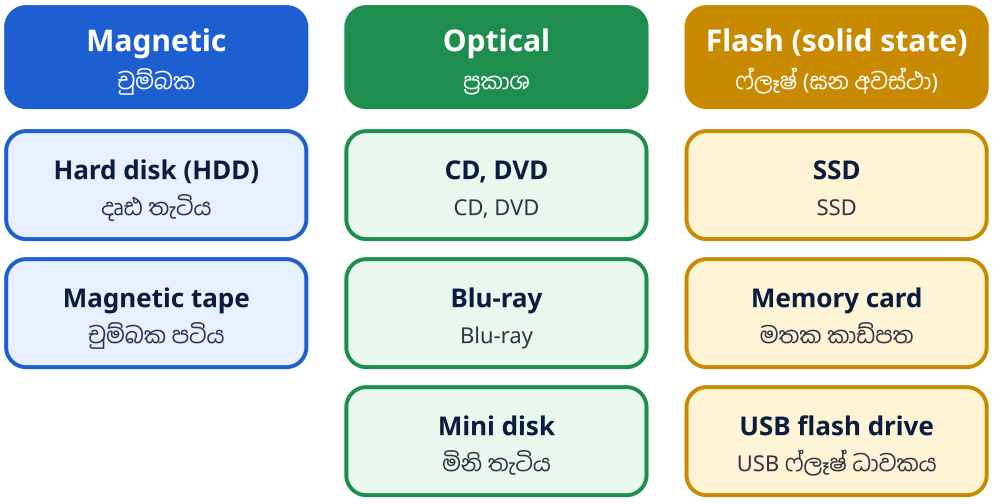
4. Peripherals and their interfaces (ports)

Interface	Typical devices
USB (Type-A, Type-C)	Keyboard, mouse, flash drive, printer, phone, external hard disk
HDMI, DisplayPort	Monitor, TV, projector (video and sound)

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VGA, DVI	Older monitors and projectors
Ethernet (RJ45)	Wired network, router
Audio jack (3.5 mm)	Speakers, headphones, microphone
SATA, M.2 (NVMe)	Internal hard disk, SSD, DVD drive
PCIe slot	Graphics card, network card
PS/2, serial, parallel (legacy)	Old keyboards, mice, printers
Bluetooth, Wi-Fi (wireless)	Wireless mouse, headset, phone, network

5. Storage devices



Magnetic, optical and flash storage.

Device	Type and access	Typical capacity	Features and uses
Fixed internal hard disk	Magnetic; direct access	1–20 TB	Spinning platters and moving heads; stores the OS and files
Portable external hard disk	Magnetic; direct access	1–5 TB	Connects by USB; backups and moving large files
Magnetic tape	Magnetic; sequential access	Up to about 18 TB per cartridge	Very cheap per GB, slow to find data; long term backups
CD-ROM / DVD-ROM	Optical; read only	CD 700 MB; DVD 4.7 GB	Data pressed at the factory; software, films
CD-R / DVD-R	Optical; write once, read many	CD 700 MB; DVD 4.7 GB	Cannot be erased; permanent records
CD-RW / DVD-RW	Optical; rewritable	CD 700 MB; DVD 4.7 GB	Erase and rewrite about 1,000 times
DVD-RAM	Optical; rewritable, random access	4.7 GB per side	Rewritten up to about 100,000 times; used like a disk; video recorders

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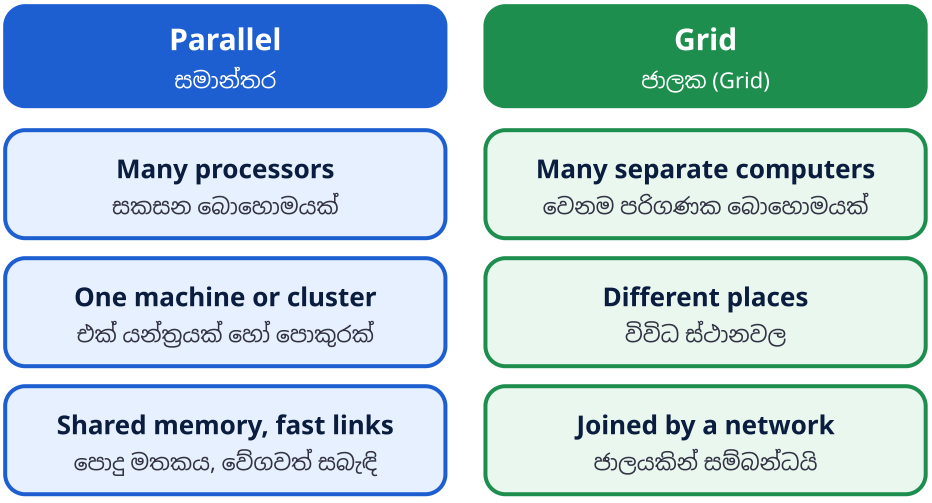
Blu-ray disc	Optical; blue-violet laser	25 GB per layer	Shorter wavelength → smaller pits → more data; HD films, games
Flash memory card	Flash (solid state); no moving parts	16 GB – 1 TB	SD, microSD; small, tough; cameras and phones
Mini disk	Magneto-optical; rewritable	About 140–177 MB (80 min audio)	Sony 1992; small disc in a case; music recording; now rare

🧱 **Worked example: How many full 700 MB CDs can be copied onto one 25 GB Blu-ray disc? (Disc makers use 1 GB = 1000 MB.)**
25 GB = 25,000 MB. 25,000 ÷ 700 = 35.7. Only whole CDs fit, so **35 CDs**.

🧱 **Worked example: A 64 GB memory card stores photos of 4 MB each. How many photos fit? (1 GB = 1000 MB)**
64 × 1000 = 64,000 MB. 64,000 ÷ 4 = **16,000 photos**.

💡 Access methods: **sequential** (tape – read from the start in order), **direct** (disks – jump near the data) and **random** (RAM and flash – any place in the same time).

6. Parallel and grid computing



Parallel computing and grid computing compared.

Parallel computing splits one big job into small parts and runs them **at the same time on many processors** in one computer or a closely linked cluster. **Grid computing** joins **many separate computers in different places** over a network so they share their processing power and storage to solve a big problem (e.g. CERN's worldwide grid, Folding@home).

- **Why we need them:** some problems are too big for one processor – weather and climate models, medical and DNA research, AI training, space science.
- **Faster results** – many parts are worked on at the same time.

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- **Lower cost** – grid computing uses idle computers that already exist instead of buying one giant machine.
- **Sharing resources** – universities and labs share data and power.

🚀 **Beyond the syllabus (2026 update)** *Not required for the exam – read for interest.* **USB4, Thunderbolt and NVMe.** In 2026 one **USB-C** port can carry data, video and power. **USB4 version 2** and **Thunderbolt 5** reach 80 Gbit/s. Inside the PC, **NVMe SSDs** plug into an M.2 slot and use PCIe lanes, reaching about 7,000 MB/s (PCIe 4.0) to 14,000 MB/s (PCIe 5.0) – many times faster than a hard disk (about 200 MB/s). Wi-Fi 7 and Bluetooth 5 connect wireless devices.

Key Words

Direct entry – Input read straight from the source without typing.

Barcode reader – A device that reads printed bars with light.

MICR – Reading characters printed in magnetic ink on cheques.

OMR – Reading pencil marks made in fixed places on a form.

OCR – Turning printed or written text into editable characters.

Digitizer – A pen and board that turn drawings into digital data.

Laser printer – A non-impact printer that uses a drum and toner.

Graph plotter – An output device that draws accurate large drawings with pens.

Motherboard – The main circuit board that connects the CPU, memory and devices.

CPU socket – The place on the motherboard where a matching CPU is fitted.

Interface (port) – A connection point between a computer and a device.

Magnetic tape – Cheap sequential access storage used for backups.

Blu-ray – An optical disc read with a blue-violet laser, 25 GB per layer.

DVD-RAM – A rewritable optical disc with random access, rewritten many times.

Grid computing – Many separate networked computers sharing power to solve one problem.

Sample Q&A

1. Give three advantages of direct entry input over keyboard entry.

> **Answer:** It is faster; it has fewer errors because nothing is typed; it needs fewer staff and can work all day, even in dangerous places (sensors).

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2. Which input device suits each: (a) cheques (b) MCQ sheets (c) supermarket items?

> **Answer:** (a) MICR reader (b) OMR reader (c) barcode reader.

3. Compare an inkjet printer and a laser printer.

> **Answer:** Inkjet sprays ink drops; it is cheap to buy and good for colour photos but ink is costly. Laser uses a drum and toner; it is faster and cheaper per page for large amounts.

4. What must you check so that a CPU is compatible with a motherboard?

> **Answer:** The socket type, the chipset and BIOS support, the RAM type (DDR4 or DDR5), the power (TDP) and the form factor of the board.

5. Distinguish CD-R, CD-RW and DVD-RAM.

> **Answer:** CD-R can be written once only. CD-RW can be erased and rewritten about 1,000 times. DVD-RAM can be rewritten about 100,000 times and is used with random access like a disk.

6. Distinguish parallel computing from grid computing.

> **Answer:** Parallel computing uses many processors in one machine or a close cluster at the same time. Grid computing joins many separate computers in different places through a network to share their power.

MCQ

1. Which is a direct entry input device?

A. Barcode reader
B. Speaker
C. Numeric keypad
D. Keyboard
E. Laser printer

2. Bank cheques are read using:

A. A touch pad
B. MICR
C. A graph plotter
D. OMR
E. A web cam

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3. The MAIN advantage of direct entry over keyboard entry is:

A. Fewer transcription errors and faster input
B. It always costs nothing
C. It stores data forever
D. It needs more staff
E. It prints the data

4. Which printer can make carbon copies of a bill?

A. 3D printer
B. Inkjet printer
C. Dot matrix printer
D. LED monitor
E. Laser printer

5. Which monitor is heavy and uses an electron beam?

A. OLED
B. CRT
C. Touch screen
D. TFT
E. LED

6. An architect needs large, accurate building plans on paper. The best device is:

A. Dot matrix printer
B. OMR reader
C. Speaker
D. Graph plotter
E. Web cam

7. Which is NOT needed for CPU and motherboard compatibility?

A. The colour of the case
B. Power (TDP)
C. RAM type
D. Chipset support
E. Socket type

8. A monitor is connected using:

A. 3.5 mm audio jack
B. PS/2
C. SATA
D. RJ45
E. HDMI

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9. Which storage uses sequential access?

A. Magnetic tape
B. Hard disk
C. Flash memory card
D. DVD-RAM
E. RAM

10. How many full 700 MB CDs fit on one 25 GB Blu-ray (1 GB = 1000 MB)?

A. 25
B. 35
C. 357
D. 36
E. 3

11. A disc that can be written only once is:

A. Hard disk
B. CD-RW
C. DVD-RAM
D. DVD-R
E. DVD-RW

12. Many university computers around the world share power to analyse physics data. This is:

A. Analog computing
B. Keyboard entry
C. Sequential access
D. Batch printing
E. Grid computing

13. Which term means: “Input read straight from the source without typing”?

A. MICR
B. Digitizer
C. Graph plotter
D. Interface (port)
E. Direct entry

14. Which term means: “A device that reads printed bars with light”?

A. OMR
B. Barcode reader
C. Laser printer
D. Motherboard
E. Magnetic tape

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15. Which term means: “Reading characters printed in magnetic ink on cheques”?

A. Blu-ray
B. OCR
C. CPU socket
D. MICR
E. Graph plotter

16. Which term means: “Reading pencil marks made in fixed places on a form”?

A. Digitizer
B. DVD-RAM
C. OMR
D. Interface (port)
E. Motherboard

17. Which term means: “Turning printed or written text into editable characters”?

A. Magnetic tape
B. Laser printer
C. CPU socket
D. OCR
E. Grid computing

18. Which term means: “A pen and board that turn drawings into digital data”?

A. Graph plotter
B. Direct entry
C. Digitizer
D. Interface (port)
E. Blu-ray

19. Which term means: “A non-impact printer that uses a drum and toner”?

A. DVD-RAM
B. Magnetic tape
C. Laser printer
D. Barcode reader
E. Motherboard

20. Which term means: “An output device that draws accurate large drawings with pens”?

A. Blu-ray
B. CPU socket
C. MICR
D. Grid computing
E. Graph plotter

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Structured Questions

1. (a) Name two keyboard entry and four direct entry input devices. (b) Give two advantages of direct entry. *(4 marks)*

> (a) Keyboard, keypad; barcode reader, OMR, MICR, sensor; (b) faster; fewer errors because there is no typing.

2. Suggest a suitable output device for each and give a reason: (a) colour photos at home (b) 5,000 school reports (c) a plastic model of a gear. *(3 marks)*

> (a) Inkjet – good colour, cheap printer; (b) laser – fast and low cost per page; (c) 3D printer – builds solid objects layer by layer.

3. A student buys an AMD AM5 CPU and an Intel LGA 1700 motherboard. (a) Will it work? Explain. (b) List two other things to check. *(3 marks)*

> (a) No – the CPU does not fit the socket; the chipset does not support it; (b) RAM type (DDR5) and power or BIOS support.

4. (a) Classify into magnetic, optical or flash: hard disk, Blu-ray, SD card, tape, DVD-RW. (b) How many 4 MB photos fit on a 64 GB card (1 GB = 1000 MB)? *(4 marks)*

> (a) Magnetic: hard disk, tape; optical: Blu-ray, DVD-RW; flash: SD card; (b) 64 × 1000 ÷ 4 = 16,000 photos.

5. Explain why weather forecasting needs parallel or grid computing. *(4 marks)*

> The model has billions of calculations; one processor would take too long; the work is split so many processors work at the same time; the forecast is ready before the weather arrives.

Summary

- Input is keyboard entry (typing) or direct entry (barcode, OMR, OCR, MICR, sensors, cameras and more).
- Direct entry is faster, more accurate, cheaper in labour and works all the time.
- Outputs: CRT, TFT, LED monitors; dot matrix, inkjet, laser and 3D printers; plotters; speakers.
- A CPU must match the motherboard socket, chipset, RAM type and power.
- Storage: magnetic (HDD, tape), optical (CD, DVD, DVD-RAM, Blu-ray, mini disk) and flash (cards, SSD).
- Parallel computing uses many processors together; grid computing joins many networked computers.

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MCQ answer key – 2.2

1. **A** – Reads data without typing.
2. **B** – Magnetic ink characters.
3. **A** – No typing step.
4. **C** – Impact printer.
5. **B** – Cathode ray tube.
6. **D** – Pens draw accurate lines.
7. **A** – Colour does not matter.
8. **E** – Video and sound.
9. **A** – Read in order from the start.
10. **B** – 25,000 ÷ 700 = 35.7 → 35.
11. **D** – Write once, read many.
12. **E** – Separate computers in different places.
13. **E** – Direct entry – Input read straight from the source without typing.
14. **B** – Barcode reader – A device that reads printed bars with light.
15. **D** – MICR – Reading characters printed in magnetic ink on cheques.
16. **C** – OMR – Reading pencil marks made in fixed places on a form.
17. **D** – OCR – Turning printed or written text into editable characters.
18. **C** – Digitizer – A pen and board that turn drawings into digital data.
19. **C** – Laser printer – A non-impact printer that uses a drum and toner.
20. **E** – Graph plotter – An output device that draws accurate large drawings with pens.

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Grade 12 A/L ICT · Lesson 2

2.3 Von Neumann Architecture: Stored Program, CPU and the Fetch–Execute Cycle

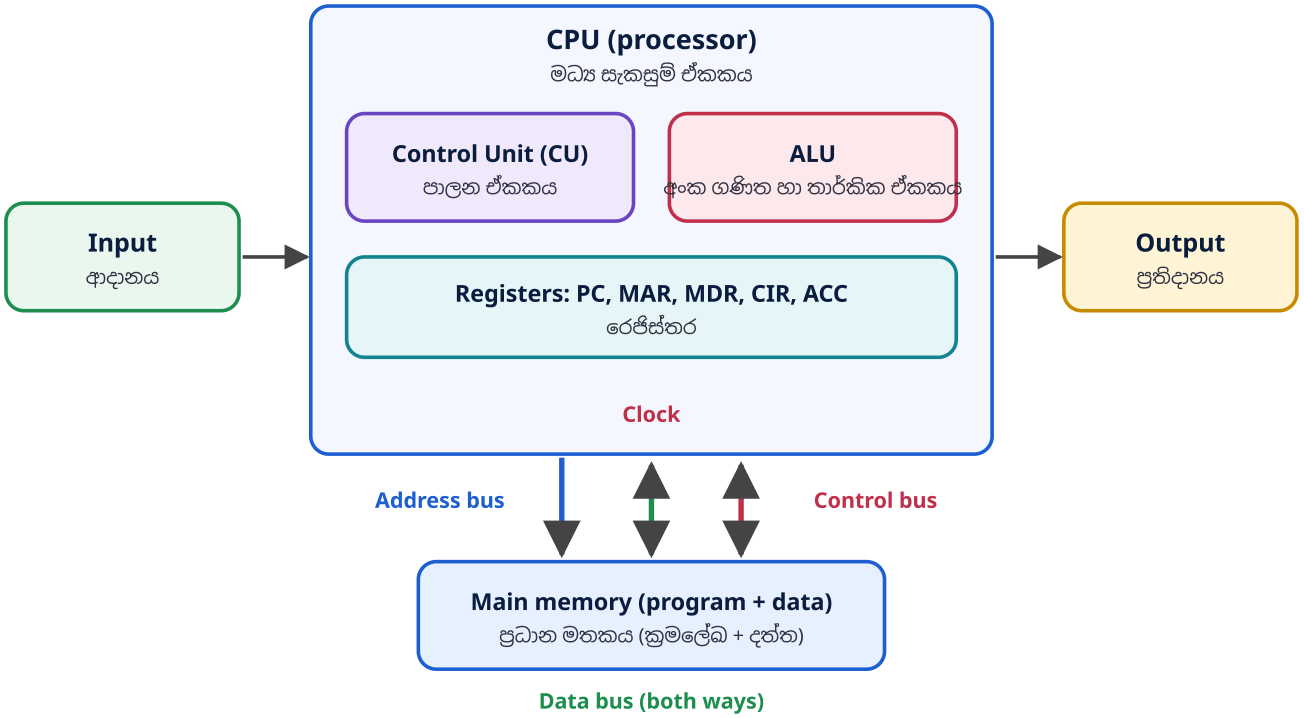
Syllabus 2.3. Almost every computer today follows one simple plan described by **John von Neumann** in 1945: keep the **program and the data together in the same memory**, and let the **CPU** fetch and run the instructions one by one. In this part you learn the **stored program concept**, the **components** of the model and how to draw it, the **fetch–execute cycle**, the jobs of the **ALU, CU, registers and buses**, and why we now use **multi-core processors**.

1. The stored program concept

Early machines such as ENIAC were programmed by **changing wires and switches** – a new job could take days. Von Neumann's idea (in his 1945 report on **EDVAC**) was: store the **instructions as numbers in memory**, exactly like data. To change the job, you just **load a different program** into memory.

- Program instructions and data are stored **together in the same main memory**.
- Every memory location has an **address**; the CPU reads and writes using addresses.
- Instructions are run **one after another (sequentially)** unless a jump instruction changes the order.

2. Components of the von Neumann model



The von Neumann architecture – learn to draw this.

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Input unit
Brings data and programs into the computer.

Memory unit
Holds both the program and the data.

Control unit (CU)
Fetches and decodes instructions and sends control signals.

Arithmetic and logic unit (ALU)
Does the calculations and comparisons.

Output unit
Sends results out to the user.

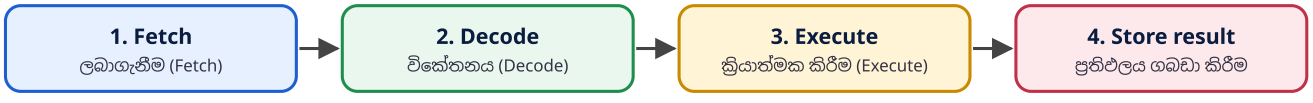
💡 When you draw the model in the exam: put the **CU and ALU (with registers) inside one CPU box**, show **memory** beside it, **input** and **output** at the sides, and label the arrows **data**, **address** and **control**.

3. Inside the CPU

Part	Job
ALU	Arithmetic (+, −, ×, ÷) and logic (AND, OR, NOT, comparing >, <, =)
Control unit (CU)	Fetches and decodes instructions, controls the timing with the clock, and directs data between parts
Registers	Tiny, very fast memory cells inside the CPU
Clock	Sends regular pulses; each pulse is one cycle

Register	What it holds
Program counter (PC)	The address of the next instruction
Memory address register (MAR)	The address to read from or write to
Memory data register (MDR / MBR)	The data or instruction just read, or about to be written
Current instruction register (CIR / IR)	The instruction being decoded and run
Accumulator (ACC)	The result from the ALU

4. The fetch–execute cycle



The CPU repeats this cycle billions of times each second.

- **Fetch:** PC → MAR; the instruction at that address comes to the MDR, then to the CIR; PC = PC + 1.
- **Decode:** the CU works out what the instruction means (the operation and the data it needs).

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- **Execute:** the CU sends signals; the ALU calculates, or data is moved, or a jump changes the PC.
- **Store:** the result is saved in the accumulator, a register or memory. Then the cycle starts again.

🧱 **Worked example: A CPU clock runs at 3.2 GHz. How long is one clock cycle?**
Cycle time = 1 ÷ frequency = 1 ÷ (3.2×10^9) s = **0.3125 ns**.

🧱 **Worked example: The same CPU needs on average 4 cycles per instruction. How many million instructions per second (MIPS) can one core run? What about 4 cores working fully in parallel?**
3.2 GHz = 3,200 million cycles per second. 3,200 ÷ 4 = **800 MIPS** per core. 4 cores: 800 × 4 = **3,200 MIPS** (best case).

5. Buses

A **bus** is a set of parallel wires that carries signals between the CPU, memory and input/output. The **system bus** has three parts:

Bus	Carries	Direction
Address bus	Memory addresses chosen by the CPU	One way: CPU → memory
Data bus	Data and instructions	Two ways
Control bus	Signals such as read, write, clock, interrupt	Two ways

🧱 **Worked example: How many memory locations can a 16-bit and a 32-bit address bus reach?**
n address lines give 2^n addresses. 2^{16} = **65,536** locations (64 K). 2^{32} = **4,294,967,296** locations (4 G).

🧱 **Worked example: A CPU has a 64-bit data bus. How many bytes can it move in one transfer?**
64 bits ÷ 8 = **8 bytes** at a time. A wider data bus moves more data per cycle.

💡 **Von Neumann bottleneck:** instructions and data share one bus to memory, so the fast CPU often waits for the slower memory. Cache memory and wider buses help reduce this.

6. Multi-core processors

A **core** is a complete processing unit (its own CU, ALU and registers). A **multi-core processor** has two or more cores on **one chip** (dual-core, quad-core, octa-core).

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- **Why needed:** making one core faster by raising the clock speed creates too much **heat** and uses too much **power**. Adding cores gives more work per second without a hotter clock.
- **Multitasking:** different programs can run on different cores at the same time.
- **Limit:** the speed-up is real only if the software is written to use many cores (multi-threaded).

🚀 **Beyond the syllabus (2026 update)** *Not required for the exam – read for interest.* **GPUs, NPUs and hybrid cores.** In 2026 a phone or laptop chip is a **system on a chip** with CPU cores plus a **GPU** (thousands of small cores for graphics and AI) and an **NPU** (neural processing unit) rated at 40+ **TOPS** (trillion operations per second) for on-device AI. Many CPUs mix **performance (P) cores** for heavy work and **efficiency (E) cores** to save battery.

Key Words

Stored program concept – Instructions and data are kept together in the same memory.

Von Neumann architecture – A computer design with input, output, memory, CU and ALU sharing one memory for program and data.

ALU – The part of the CPU that does arithmetic and logic operations.

Control unit – The part of the CPU that fetches, decodes and controls the running of instructions.

Register – A tiny, very fast memory location inside the CPU.

Program counter – The register that holds the address of the next instruction.

Accumulator – The register that holds the result of the ALU.

Fetch–execute cycle – The repeated steps fetch, decode and execute that the CPU follows.

Address bus – One-way bus that carries memory addresses from the CPU.

Data bus – Two-way bus that carries data and instructions.

Control bus – Bus that carries control signals such as read, write and clock.

Clock speed – The number of cycles per second, measured in hertz (GHz).

Multi-core processor – A chip with two or more complete processing cores.

Von Neumann bottleneck – The CPU waiting for memory because program and data share one bus.

EDVAC – Early computer in whose 1945 report the stored program idea was described.

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Sample Q&A

1. What is the stored program concept?

> **Answer:** Program instructions are stored in main memory together with the data, so the CPU can fetch and run them one by one, and a new program can be loaded without rewiring.

2. Name the five main components of the von Neumann model.

> **Answer:** Input unit, output unit, memory unit, control unit (CU) and arithmetic and logic unit (ALU).

3. Describe the fetch stage of the cycle.

> **Answer:** The address in the PC is copied to the MAR; the instruction at that address is read into the MDR and copied to the CIR; the PC is increased by one.

4. Compare the address bus and the data bus.

> **Answer:** The address bus carries addresses one way from the CPU and its width decides how many locations can be reached. The data bus carries data both ways and its width decides how much is moved at once.

5. What does the ALU do? Give examples.

> **Answer:** It does arithmetic such as addition and subtraction and logic such as AND, OR, NOT and comparing two numbers.

6. Why are multi-core processors needed?

> **Answer:** Raising the clock speed makes too much heat and uses too much power, so more cores are added to do more work at the same time and to run many programs together.

MCQ

1. In the von Neumann architecture, programs and data are stored:

A. Only on the hard disk
B. Together in the same memory
C. In the output unit
D. In separate wires and switches
E. Only in the ALU

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2. Which register holds the address of the next instruction?

A. MDR
B. ALU
C. Program counter (PC)
D. Accumulator
E. CIR

3. Which bus is one-way only?

A. Data bus
B. All buses
C. USB bus
D. Address bus
E. Control bus

4. Comparing two numbers to see which is bigger is done by the:

A. Control bus
B. ALU
C. Program counter
D. MAR
E. Input unit

5. What is the cycle time of a 3.2 GHz clock?

A. 0.32 s
B. 3.2 ns
C. 1 ns
D. 312.5 ns
E. 0.3125 ns

6. A 16-bit address bus can address:

A. 256 locations
B. 4,294,967,296 locations
C. 16 locations
D. 32,768 locations
E. 65,536 locations

7. The correct order of the cycle is:

A. Fetch → decode → execute
B. Decode → fetch → execute
C. Fetch → execute → decode
D. Execute → fetch → decode
E. Store → decode → fetch

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8. The main reason for multi-core processors is:

A. Keyboards became faster
B. Hard disks need cores
C. Higher clock speeds cause too much heat and power use
D. Buses were removed
E. Memory became cheaper

9. A 64-bit data bus moves how many bytes at once?

A. 8
B. 64
C. 512
D. 16
E. 4

10. The von Neumann bottleneck happens because:

A. The CPU has too many cores
B. Program and data share one path to memory
C. Output is too fast
D. The ALU has no registers
E. There is no clock

11. Read and write signals travel on the:

A. Control bus
B. Program counter
C. Address bus
D. Output unit
E. Accumulator

12. A 3.2 GHz core needs 4 cycles per instruction. Its speed is:

A. 80 MIPS
B. 400 MIPS
C. 3,200 MIPS
D. 12.8 MIPS
E. 800 MIPS

13. Which term means: “Instructions and data are kept together in the same memory”?

A. Program counter
B. Fetch–execute cycle
C. Control bus
D. Stored program concept
E. ALU

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14. Which term means: “A computer design with input, output, memory, CU and ALU sharing one memory for program and data”?

A. Accumulator
B. Clock speed
C. Address bus
D. Von Neumann architecture
E. Control unit

15. Which term means: “The part of the CPU that does arithmetic and logic operations”?

A. Fetch–execute cycle
B. Data bus
C. ALU
D. Register
E. Multi-core processor

16. Which term means: “The part of the CPU that fetches, decodes and controls the running of instructions”?

A. Control unit
B. Von Neumann bottleneck
C. Program counter
D. Address bus
E. Control bus

17. Which term means: “A tiny, very fast memory location inside the CPU”?

A. Accumulator
B. Clock speed
C. Register
D. EDVAC
E. Data bus

18. Which term means: “The register that holds the address of the next instruction”?

A. Fetch–execute cycle
B. Stored program concept
C. Control bus
D. Program counter
E. Multi-core processor

19. Which term means: “The register that holds the result of the ALU”?

A. Von Neumann architecture
B. Accumulator
C. Address bus
D. Clock speed
E. Von Neumann bottleneck

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20. Which term means: “The repeated steps fetch, decode and execute that the CPU follows”?

A. Multi-core processor
B. EDVAC
C. Data bus
D. ALU
E. Fetch–execute cycle

Structured Questions

1. (a) State the stored program concept. (b) Why was it an improvement over ENIAC? *(3 marks)*

> (a) Instructions and data are stored together in main memory; instructions are fetched and run one by one; (b) ENIAC was rewired for each job, now a new program is simply loaded.

2. Draw a labelled diagram of the von Neumann architecture showing the buses. *(5 marks)*

> CPU box containing CU, ALU and registers; memory unit; input unit; output unit; address, data and control buses labelled with correct directions.

3. Explain the fetch–execute cycle using PC, MAR, MDR and CIR. *(5 marks)*

> PC copied to MAR; instruction read into MDR; copied to CIR and PC increased; CU decodes the instruction; ALU or CU executes it and the result is stored.

4. A computer has a 32-bit address bus and a 64-bit data bus. (a) How many locations can it address? (b) How many bytes move in one transfer? *(2 marks)*

> (a) 2^{32} = 4,294,967,296 locations; (b) 64 ÷ 8 = 8 bytes.

5. (a) What is a multi-core processor? (b) Give two advantages and one limitation. *(4 marks)*

> (a) A chip with two or more complete cores; (b) more work at the same time without a hotter clock; better multitasking; limitation: software must be multi-threaded to benefit.

Summary

- Stored program concept: program and data together in one memory (von Neumann, 1945, EDVAC).
- Components: input, output, memory, control unit and ALU.
- The CPU repeats fetch → decode → execute → store using PC, MAR, MDR, CIR and ACC.
- The address bus is one-way; data and control buses are two-way.
- n address lines reach 2^n locations; a 64-bit data bus moves 8 bytes at once.
- Multi-core chips give more work per second without too much heat.

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MCQ answer key – 2.3

1. **B** – Stored program concept.
2. **C** – PC points to the next instruction.
3. **D** – CPU → memory.
4. **B** – A logic operation.
5. **E** – 1 ÷ 3.2 = 0.3125 ns.
6. **E** – 2^{16} = 65,536.
7. **A** – Fetch first, then decode, then execute.
8. **C** – Heat and power limit.
9. **A** – 64 ÷ 8 = 8.
10. **B** – CPU waits for memory.
11. **A** – Control signals.
12. **E** – 3,200 ÷ 4 = 800.
13. **D** – Stored program concept – Instructions and data are kept together in the same memory.
14. **D** – Von Neumann architecture – A computer design with input, output, memory, CU and ALU sharing one memory for program and data.
15. **C** – ALU – The part of the CPU that does arithmetic and logic operations.
16. **A** – Control unit – The part of the CPU that fetches, decodes and controls the running of instructions.
17. **C** – Register – A tiny, very fast memory location inside the CPU.
18. **D** – Program counter – The register that holds the address of the next instruction.
19. **B** – Accumulator – The register that holds the result of the ALU.
20. **E** – Fetch–execute cycle – The repeated steps fetch, decode and execute that the CPU follows.

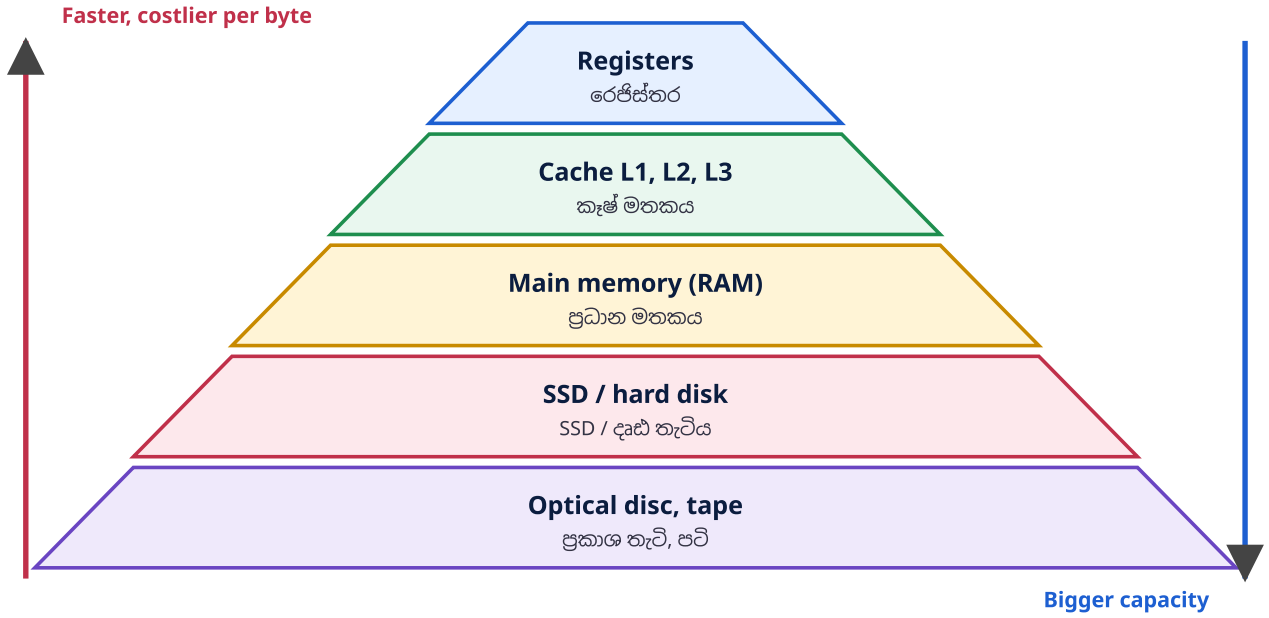
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Grade 12 A/L ICT · Lesson 2

2.4 Memory Hierarchy: Registers, Cache, RAM, ROM and Secondary Storage

Syllabus 2.4. No single memory is fast, big and cheap at the same time. So a computer uses a **memory hierarchy**: a small amount of very fast, costly memory near the CPU, and large amounts of slower, cheaper memory further away. In this part you learn **why** we need the hierarchy, the **comparison criteria**, **volatile** memory (registers, cache, RAM – SRAM, DRAM, SDRAM), **non-volatile** memory (PROM, EPROM, EEPROM and secondary storage), and how to **compare** them by access time, cost per MB and capacity.

1. The memory hierarchy



Top: fastest, smallest, most costly. Bottom: slowest, largest, cheapest.

Think of a student's books: the page you are reading is in your hand (**registers**), a few books are on the desk (**cache**), more are on the shelf in the room (**RAM**), and the rest are in the library (**secondary storage**). What you use most is kept closest.

- **Why needed:** fast memory is very costly, so we cannot have gigabytes of it; cheap memory is slow. The hierarchy gives **speed close to the fastest level at a cost close to the cheapest**.
- It works because programs mostly reuse the **same data and nearby data** (locality), so copies kept in fast memory are used again and again.
- We also need **non-volatile** storage so data is not lost when the power goes off.

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2. Comparison criteria

Criterion	Meaning
Physical size / density	How much data fits in a given space (bits per area)
Access method	Random (RAM), direct (disk) or sequential (tape)
Access time	Delay from asking for data to getting it
Capacity	How much data it can hold
Cost	Price per MB or GB
Volatility	Is data lost without power?
Location	Inside the CPU, on the motherboard, or outside
Physical arrangement	How bits are grouped into words (e.g. 8, 32 or 64 bits)

3. Volatile memory

Volatile memory loses its contents when the power is switched off.

Registers
Inside the CPU; fastest; hold only a few values being worked on now.

Cache memory
Fast SRAM between CPU and RAM that keeps copies of often used data. **L1** (smallest, fastest, in each core), **L2** (larger), **L3** (largest, shared by cores).

Main memory (RAM)
Holds the running programs and their data; random access; read and write.

Type of RAM	How it stores a bit	Features	Used for
SRAM (static)	Flip-flop of about 6 transistors	Very fast, no refresh, costly, low density	Cache memory
DRAM (dynamic)	Tiny capacitor + 1 transistor	Needs refreshing thousands of times a second; cheaper, high density, slower	Main memory
SDRAM (synchronous DRAM)	DRAM that works in step with the system clock	Faster than plain DRAM; DDR, DDR4, DDR5 are types of SDRAM	Modern PC RAM

4. Non-volatile memory

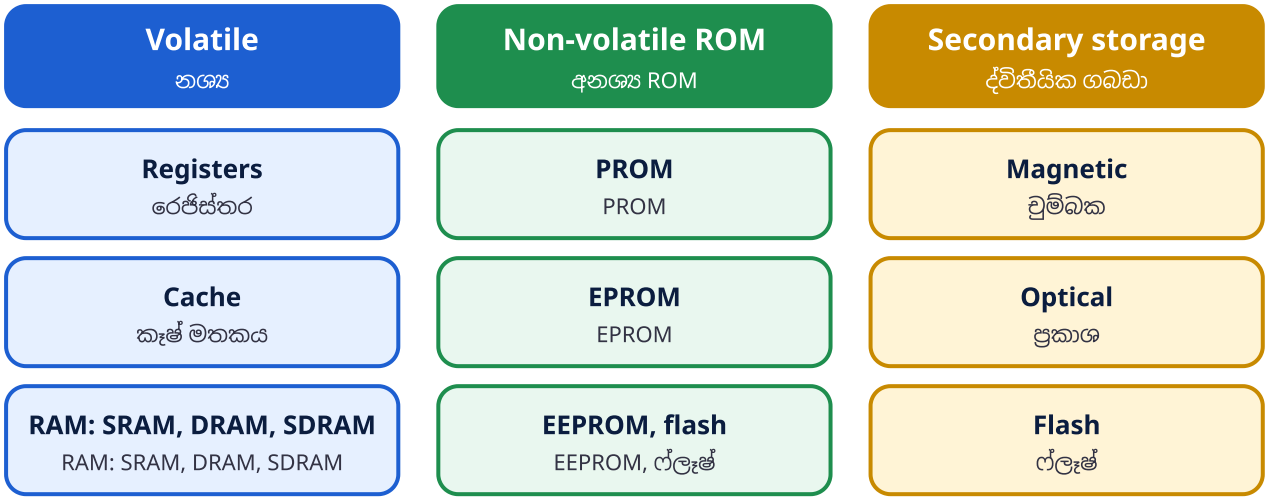
Non-volatile memory keeps its contents without power. ROM holds the start-up program (BIOS/UEFI firmware).

Type	How it is written	Can it be erased?

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ROM (mask ROM)	Written at the factory	No
PROM	Blank; programmed **once** by the user with a special device	No – one time only
EPROM	Programmed electrically	Yes – whole chip erased by **ultraviolet light** through a quartz window, then reprogrammed
EEPROM	Programmed electrically inside the computer	Yes – **electrically**, byte by byte, without removing it; flash memory is a fast block-erase type

Secondary storage is non-volatile and large: **magnetic** (hard disk, tape), **optical** (CD, DVD, Blu-ray) and **flash** (SSD, memory cards, pen drives). It is not directly used by the CPU – data is first copied into RAM.



Volatile and non-volatile memory types.

5. Comparing the levels

Memory	Typical access time	Typical capacity	Cost per MB
Registers	< 1 ns	Bytes (a few hundred)	Highest
Cache (L1, L2, L3)	1–20 ns	KB to tens of MB	Very high
Main memory (RAM)	50–100 ns	4–64 GB	Medium
SSD (flash)	about 0.1 ms	256 GB – 4 TB	Low
Hard disk (HDD)	about 10 ms	1–20 TB	Very low
Optical disc / tape	100 ms to minutes	GB (disc) to TB (tape)	Lowest

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🧱 **Worked example: A CPU finds data in cache 95% of the time (2 ns). Otherwise it reads RAM (80 ns). Using the simple model, what is the average access time?**
Average = 0.95 × 2 + 0.05 × 80 = 1.9 + 4.0 = **5.9 ns**. Much closer to cache speed than RAM speed – that is why cache helps.

🧱 **Worked example: A hard disk access takes 10 ms and RAM takes 50 ns. How many times slower is the hard disk?**
10 ms = 10,000,000 ns. 10,000,000 ÷ 50 = **200,000 times slower**.

🧱 **Worked example: A computer has 8 GB of byte-addressable RAM. How many bytes is that, and how many address lines are needed? How many 64-bit words does it hold?**
8 GB = 8 × 2^{30} = 2^{33} = **8,589,934,592 bytes**, so **33 address lines**. One 64-bit word = 8 bytes, so 8,589,934,592 ÷ 8 = **1,073,741,824 words**.

💡 Memory units here use powers of 2: 1 KB = 1024 bytes, 1 MB = 1024 KB, 1 GB = 1024 MB = 2^{30} bytes.

🚀 **Beyond the syllabus (2026 update)** *Not required for the exam – read for interest.* **DDR5, HBM and PCIe 5.0 SSDs.** In 2026 new PCs use **DDR5** SDRAM (about 4,800–8,000 MT/s), and phones use **LPDDR5X**. AI graphics chips stack DRAM layers on top of each other as **HBM3E** (high bandwidth memory) to feed thousands of cores. **PCIe 5.0 NVMe SSDs** read at about 14,000 MB/s, closing part of the gap between RAM and storage. New non-volatile ideas such as MRAM are being tested.

Key Words

Memory hierarchy – Arranging memory from small, fast and costly to large, slow and cheap.

Volatile memory – Memory that loses its contents when power is off.

Non-volatile memory – Memory that keeps its contents without power.

Cache memory – Small fast SRAM between the CPU and RAM holding often used data.

SRAM – Static RAM made of flip-flops; fast and needs no refresh.

DRAM – Dynamic RAM made of capacitors; must be refreshed.

SDRAM – DRAM synchronised with the system clock, e.g. DDR5.

PROM – ROM that the user can program only once.

EPROM – ROM erased with ultraviolet light and reprogrammed.

EEPROM – ROM erased and rewritten electrically inside the circuit.

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Access time – The delay between asking for data and receiving it.

Random access – Any location can be reached in the same time.

Secondary storage – Large non-volatile storage such as disks and flash drives.

Word – A group of bits handled together by the CPU, e.g. 64 bits.

Refresh – Recharging DRAM cells regularly so data is not lost.

Sample Q&A

1. Why does a computer need a memory hierarchy?

> **Answer:** Fast memory is very costly and small, cheap memory is slow. Mixing levels gives speed near the fastest level at a cost near the cheapest, and non-volatile levels keep data without power.

2. Distinguish volatile and non-volatile memory with two examples each.

> **Answer:** Volatile memory loses data without power (registers, cache, RAM). Non-volatile keeps data (ROM, EEPROM, hard disk, SSD).

3. Compare SRAM and DRAM.

> **Answer:** SRAM uses flip-flops, needs no refresh, is fast and costly and is used for cache. DRAM uses capacitors, needs refreshing, is slower, cheaper and denser and is used for main memory.

4. How do PROM, EPROM and EEPROM differ?

> **Answer:** PROM can be programmed once only. EPROM is erased with ultraviolet light and reprogrammed. EEPROM is erased and rewritten electrically without removing it.

5. What is cache memory and why are there L1, L2 and L3 levels?

> **Answer:** Cache is fast SRAM that keeps copies of often used data near the CPU. L1 is smallest and fastest, L3 is larger and shared, so each level is a balance of speed and size.

6. List the levels from fastest to slowest.

> **Answer:** Registers, cache, main memory (RAM), SSD, hard disk, optical disc and tape.

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MCQ

1. Which memory is the fastest?

A. RAM
B. Cache
C. Registers
D. SSD
E. Hard disk

2. Which is volatile?

A. DRAM
B. PROM
C. Hard disk
D. Blu-ray
E. EEPROM

3. Cache memory is usually made of:

A. PROM
B. EPROM
C. Magnetic tape
D. DRAM
E. SRAM

4. Which memory must be refreshed regularly?

A. PROM
B. DRAM
C. Registers
D. EPROM
E. SRAM

5. EPROM is erased using:

A. It cannot be erased
B. A magnet
C. Ultraviolet light
D. Electric signals byte by byte
E. A laser printer

6. ROM that can be programmed only once by the user is:

A. EPROM
B. EEPROM
C. SDRAM
D. PROM
E. Flash

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7. Moving down the hierarchy, which INCREASES?

A. Closeness to the CPU
B. Speed
C. Cost per MB
D. Capacity
E. Volatility

8. With 95% cache hits at 2 ns and misses at 80 ns, the average access time (simple model) is:

A. 41 ns
B. 5.9 ns
C. 2 ns
D. 82 ns
E. 7.6 ns

9. DDR5 is a type of:

A. Optical disc
B. Register
C. EPROM
D. SRAM
E. SDRAM

10. How many address lines are needed for 8 GB of byte-addressable memory?

A. 33
B. 32
C. 8
D. 64
E. 30

11. A hard disk (10 ms) compared with RAM (50 ns) is about:

A. 2,000 times faster
B. 200,000 times slower
C. 200 times slower
D. 20 times slower
E. 5 times slower

12. The BIOS/UEFI start-up program is stored in:

A. The data bus
B. Registers
C. Non-volatile ROM or flash
D. DRAM
E. Cache

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13. Which term means: “Arranging memory from small, fast and costly to large, slow and cheap”?

A. DRAM
B. Non-volatile memory
C. Access time
D. PROM
E. Memory hierarchy

14. Which term means: “Memory that loses its contents when power is off”?

A. Volatile memory
B. EPROM
C. Random access
D. Cache memory
E. SDRAM

15. Which term means: “Memory that keeps its contents without power”?

A. EEPROM
B. SRAM
C. Secondary storage
D. Non-volatile memory
E. PROM

16. Which term means: “Small fast SRAM between the CPU and RAM holding often used data”?

A. Access time
B. EPROM
C. DRAM
D. Cache memory
E. Word

17. Which term means: “Static RAM made of flip-flops; fast and needs no refresh”?

A. SDRAM
B. Random access
C. Refresh
D. EEPROM
E. SRAM

18. Which term means: “Dynamic RAM made of capacitors; must be refreshed”?

A. Secondary storage
B. DRAM
C. Memory hierarchy
D. PROM
E. Access time

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19. Which term means: “DRAM synchronised with the system clock, e.g. DDR5”?

A. Random access
B. Word
C. SDRAM
D. EPROM
E. Volatile memory

20. Which term means: “ROM that the user can program only once”?

A. PROM
B. EEPROM
C. Secondary storage
D. Non-volatile memory
E. Refresh

Structured Questions

1. (a) Draw the memory hierarchy pyramid. (b) State how speed, capacity and cost change from top to bottom. *(4 marks)*

> (a) Registers, cache, RAM, secondary storage (SSD/HDD), off-line (optical/tape) in order; (b) speed falls; capacity rises; cost per MB falls.

2. Classify as volatile or non-volatile: SRAM, EEPROM, DRAM, PROM, hard disk, registers. *(2 marks)*

> Volatile: SRAM, DRAM, registers; non-volatile: EEPROM, PROM, hard disk.

3. Compare SRAM and DRAM under: (a) how a bit is stored (b) refresh (c) speed and cost (d) use. *(4 marks)*

> (a) SRAM flip-flop, DRAM capacitor; (b) SRAM none, DRAM needs refresh; (c) SRAM faster and costlier; (d) SRAM cache, DRAM main memory.

4. Cache hits 95% of the time at 2 ns; misses read RAM at 80 ns. (a) Find the average access time. (b) Why does cache improve performance? *(3 marks)*

> (a) 0.95 × 2 + 0.05 × 80 = 5.9 ns; (b) most data is found in fast cache because programs reuse nearby data; the CPU waits less for RAM.

5. Explain PROM, EPROM and EEPROM and give a use of EEPROM or flash. *(4 marks)*

> PROM programmed once; EPROM erased by ultraviolet light; EEPROM erased electrically in the circuit; use: BIOS/UEFI firmware updates or pen drives.

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Summary

- No memory is fast, large and cheap at once, so a hierarchy is used.
- Criteria: density, access method, access time, capacity, cost, volatility, location.
- Volatile: registers, cache (SRAM), main memory (DRAM, SDRAM).
- Non-volatile: PROM (once), EPROM (UV erase), EEPROM (electrical erase), and secondary storage.
- Going down: slower access, bigger capacity, lower cost per MB.
- Secondary storage is magnetic, optical or flash and is copied to RAM before use.

MCQ answer key – 2.4

1. **C** – Inside the CPU.
2. **A** – Loses data without power.
3. **E** – Fast, no refresh.
4. **B** – Capacitors leak charge.
5. **C** – Quartz window.
6. **D** – Programmable ROM.
7. **D** – Bigger and cheaper.
8. **B** – 1.9 + 4 = 5.9.
9. **E** – Synchronous DRAM.
10. **A** – 2^{33} bytes.
11. **B** – 10,000,000 ÷ 50.
12. **C** – Must survive power off.
13. **E** – Memory hierarchy – Arranging memory from small, fast and costly to large, slow and cheap.
14. **A** – Volatile memory – Memory that loses its contents when power is off.
15. **D** – Non-volatile memory – Memory that keeps its contents without power.
16. **D** – Cache memory – Small fast SRAM between the CPU and RAM holding often used data.
17. **E** – SRAM – Static RAM made of flip-flops; fast and needs no refresh.
18. **B** – DRAM – Dynamic RAM made of capacitors; must be refreshed.
19. **C** – SDRAM – DRAM synchronised with the system clock, e.g. DDR5.
20. **A** – PROM – ROM that the user can program only once.

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